NASA TECHNICAL TRANSLATION NASA TT F-15,260

INTERPRETATION OF THE MEASUREMENT OF ILLUMINATION ON THE VENERA 8 INTERPLANETARY AUTOMATIC STATION

H. L. Lukashevich, M. Ya. Marov, and Ye. M. Feygel'son

Translation of "Interpretatsiya izmereniy osveshchennosti na avtomaticheskoy mezhplanetnoy stantsii 'Venera-8'," Institute of Applied Mathematics, Academy of Sciences, USSR, Moscow, Preprint No. 63, 1973, 20 pages

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JANUARY 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,260	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle INTERPRETATION OF THE MEASUREMENT OF ILLUMINATION ON THE VENERA 8 INTERPLANETARY AUTOMATIC STATION		5. Report Date January 1974
		6. Performing Organization Code
7. Author(s) H. L. Lukashevich, M. Ya. Marov, and Ye. M. Feygel'son		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No. NASw-2481
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Interpretatsiya izmereniy osveshchennosti na avtomaticheskoy mezhplanetnoy stantsii 'Venera-8'," Institute of Applied Mathematics, Academy of Sciences USSR, Moscow, Preprint No. 63, 1973, 20 pages

16. Abstract Illumination in the Venusian atmosphere was first measured on the Venera 8 Automatic Station. The principal finding was that the dense Venusian molecular atmosphere enclosed from above by the cloud layer transmits solar light to the planetary surface, though very greatly attenuated. Two atmospheric layers with differing optical density were also found: from 50 to 35 km and from 35 km to the surface. Two models of the Venusian atmosphere were examined to find the one providing closer agreement between theoretical and calculated light flux values for several atmospheric layers. The second model postulating spreading of the cloud layer downward from its base of 60 km to the 35 km level was found to yield closer agreement.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 19	22. Price 3.00

NASA-HQ

INTERPRETATION OF THE MEASUREMENT OF ILLUMINATION ON THE VENERA 8 INTERPLANETARY AUTOMATIC STATION

H. L. Lukashevich, M. Ya. Marov, and Ye. M. Feygel'son

The first experiment measuring light flux (illumination) in the atmosphere of Venus was conducted on the Venera 8 Automatic Station. A detailed description of the method and results of the measurements in the altitude range from 50 km to the surface is given in the paper [1]. /3*

The instruments installed on the station, whose sensitive elements were cadmium sulfide photocells, were capable of measuring a flux of radiative energy from the upper hemisphere. The following vertical profile was obtained for the quantity:

$$F_{\downarrow}(z) = \int_{\lambda_1}^{\lambda_2}\int_{0}^{2\pi}\int_{-1}^{0} I_{\lambda}(z, \mu, \psi)\, \mu\, d\mu\, d\psi\, d\lambda \qquad (1)$$

where I_{λ} is the spectral density of solar radiation of wavelength λ and altitude z over the planetary surface in the direction r, characterized by an angle with its external verticals at the landing site, arc cos μ and with an azimuthal angle measured from the solar vertical ψ. The solar radiation flux $F_{\downarrow}(z)$ was integrated over the wavelength spectrum in the range from $\lambda_1 = 0.4$ to $\lambda_2 = 0.8$ μm corresponding to the relative spectral sensitivity of the instruments. The effective wavelength $\lambda_{eff} = 0.63$ μm.

The distribution along the vertical of the measured radiative energy flux together with the limits of measurement error are shown in Fig. 1. The mean zenithal angle of the sun during the

* Numbers in the margin indicate pagination in the foreign text.

measurement period in the landing area was $\zeta = 84.5 \pm 2.5°$. Measurement of the entire profile took 55 min.

The direct and main result of the measurements was that the dense molecular atmosphere of Venus enclosed from above by the cloud layer transmits solar light all the way to the surface, though it very greatly weakens it. The magnitude of the radiative flux at the surface proved to be approximately 1% of the solar energy /4 arriving at the planet for $\zeta \approx 84.5°$ for $\lambda_{eff} \approx 0.63$ μm. If we compare the measured illumination of the planetary surface $F_{\downarrow}(0) =$ $= 300$ lux with the illumination of the earth for the same low position of the sun, $F_{\downarrow\,earth}(0) \approx 5000$ lux, we see that the former is only 1/16 of the latter [4]. This comparison is, however, very approximate since it was made on the assumption that the spectral composition of the light flux is virtually equal to the solar flux. Still, the spectral characteristic of the dense Venusian atmosphere is shifted toward the predominance of red rays.

Another direct result of the optical measurements was the discovery in the Venusian atmosphere of two layers with different optical density: from 50 to 35 km and from 35 km to the surface. Light is attenuated approximately by sevenfold in the layer between 70 and 50 km, by three times in the layer between 50 and 35 km, and by 5.5 times in the layer 35-0 km. Thus, the optical density of the atmosphere decreases with increase in molecular density.

The effort to extract information on atmospheric properties determining the magnitude and vertical structure of the measured radiative flux profile requires a solution to a problem that belongs to the "reciprocal" class. However, the shortage of data on the optical properties of the Venusian atmosphere hinders the use of the modern theory of the solution of reciprocal problems [5-7]. It is simpler to use the selection method, that is, by analyzing a number of atmospheric models, to find the one for which the calculated vertical profile of the flux $F_{\downarrow}(z)$ proves to be closer to the measured profile.

Previously it may have been held that the solution to the problem will not be unique because of the fairly large number of parameters determining the magnitude of $F_{\downarrow}(z)$. Leaving to one side the numerous secondary parameters, let us specify the principal ones: the scattering coefficient -- $\sigma_{\lambda}(z)$, the absorption coefficient -- $\alpha_{\lambda}(z)$, and the scattering function or the indicatrix -- $\gamma_{\lambda}(z,\phi)$, where ϕ is the scattering angle. /5

What do we know about these parameters as applied to the Venusian atmosphere with $z \leq 50$ km, that is, in the layer where the optical measurements were made?

It is natural to regard this layer as a two-component system: a molecular atmosphere and particles suspended in it -- the aerosol. Obtaining information about the aerosol essentially is the main goal of our investigation.

The molecular component of the atmosphere is well known as the result of the flights of Venera 4 to Venera 8 Interplanetary Automatic Stations [8, 15]. Scattering of light at molecules obeys Rayleigh's law and is described by the scattering coefficient

$$\sigma_{\lambda,R}(z) = \sigma_{\lambda_0,R}(z)\left(\frac{\lambda_0}{\lambda}\right)^4 \qquad (2)$$

and by the scattering indicatrix

$$\gamma_R(\varphi) = \frac{3}{4}\left(1 + \cos^2\varphi\right) \qquad (3)$$

The parameter $\sigma_{\lambda_0,R}(z)$ is presented in [9] (for $\lambda_0 = 0.5$ μm). The situation is more difficult in the determination of the absorption coefficient of the molecular constituent $\alpha_{\lambda,R}(z)$. In the spectral interval of interest, there are practically no CO_2 lines and bands, therefore we can assume $\alpha_{\lambda,R}(z) \equiv 0$. However, we must bear in mind the possibility that $\alpha_{\lambda,R}(z) > 0$ when $z \leq 40$ km or $p \geq 5$ atm (p is atmospheric pressure) due to absorption at CO_2 molecular complexes [3].

Some absorption can be assumed when $\lambda \leq 0.6$ μm even in the higher atmospheric layers based on the reflection spectrum of the planet, however this absorption is more properly attributed to the aerosol [2, 3, 9].

Thus, we know nearly all we need to calculate fluxes in a purely molecular atmosphere and we actually know nothing about the optical properties of the aerosol. We can only state that with increase in the aerosol contribution, the parameters $\sigma_\lambda(z)$ and $\alpha_\lambda(z)$ will increase compared with $\sigma_{\lambda,R}$ and $\alpha_{\lambda,R}$, and the form of the function $\gamma(z)$ will change. On analogy with earth conditions we will assume that the scattering indicatrix will be shifted the more forward, the coarser the particles, which by the Mie theory is valid for spherical particles and several other particle shapes. /6

In the conditions described the following procedure is quite reasonable: calculate, by solving the radiation transfer equation [10, 11], the flux for a purely molecular atmosphere, and then investigate how this quantity changes with increase in σ, α, and the elongation of the scattering indicatrix. The practical parameters of the transfer equation differ from those introduced above and reduced to the optical thickness

$$\tau(z) = \int_0^z \sigma(z)\, dz \qquad (4)$$

the albedo of unit volume

$$\omega(z) = \frac{\sigma(z)}{\alpha(z) + \sigma(z)} \qquad (5)$$

and to several parameters of the scattering indicatrix.

To determine the latter, let us discuss the possible methods of calculation. A numerical solution of the transfer equations provides us with massive material for optimization with respect to the initial parameters, but requires extensive information on the scattering indicatrix. Asymptotic methods [10-13] and several variants of two-flux approximations [10, 14] are wholly applicable for the conditions of the optically dense, intensely scattering Venusian atmosphere.

Here, the following indicatrix parameters are simple and convenient for tabulation:

a) the mean cosine of the scattering angle /7

$$x_1 = \frac{1}{6}\int_{-1}^{1} \gamma(\varphi) \cos\varphi \, d(\cos\varphi) \qquad (6)$$

or the parameter

$$\ell = \frac{4}{3 - x_1} \qquad (6')$$

b) the elongation of the scattering indicatrix or the difference between the fractions of light scattered in the upper and lower hemispheres with respect to the external normal to the surface

$$\Gamma = \frac{1}{2}\int_0^1 \left\{ \int_0^1 \gamma(\mu,\mu')\,d\mu' - \int_{-1}^0 \gamma(\mu,\mu')\,d\mu' \right\} d\mu \qquad (7)$$

where arc cos μ and arc cos μ' are the vertical angles of the direction of the incidence and scattering of light [14].

In this study we used both variants of the approximate methods and thus both parameters ℓ and Γ. Several results of virtually exact numerical solutions were used to estimate the precision of the approximate solutions. Generally, the calculations were made in the Schwarzchild approximation generalized for the case of nonisotropic scattering. Assuming in the style of the Schwarzchild approximation

$$\int_0^1 I\, d\omega = 2F \qquad (8)$$

$$\int_0^1 I\gamma\, d\omega = 2F\int_0^1 \gamma\, d\omega \qquad (9)$$

we arrive at the equations

$$\frac{1}{2}\cdot\frac{d(F_\uparrow - F_\downarrow)}{d\tau} = -(1-\omega)(F_\uparrow + F_\downarrow) \qquad (10)$$

$$-\frac{1}{2}\cdot\frac{d(F_\uparrow + F_\downarrow)}{d\tau} = (F_\uparrow - F_\downarrow)q \qquad (11)$$

where $F_\uparrow$ and $F_\downarrow$ are the fluxes of the ascending and descending /8
radiation, and $q = 1 - \omega\Gamma$.

Selection of the Schwarzchild approximation is dictated by the fact that this method yields virtually exact results for the principal model of Rawleigh scattering (cf. Fig. 1). For strongly elongated indicatrices ($\ell \approx 4$, $\Gamma \approx 0.73$), the method error is 9-12% in reflection and 12-16% in transmission [13].

Let us turn to equations (10) and (11). They are written for the layer satisfying the following conditions:

1.

$$\omega = \frac{\sigma_0(z)}{\alpha_0(z) + \sigma_0(z)} = const \qquad (12)$$

that is, it is assumed that the scattering and absorbing components in the layer are distributed identically with altitude;

2.

$$\gamma(z, \varphi) = \gamma(\varphi) \qquad (13)$$

that is, the scattering law does not change with altitude.

Fig. 1 gives examples of the calculation of flux based on the asymptotic formulas and by the Schwarzchild method for such a homogeneous or single-layer atmosphere with $\sigma_\lambda(z) = \sigma_{R,\lambda_{eff}}(z)$; $\gamma(\phi) = \gamma_R(\phi)$; ($\ell = 4/3$), and for a specified A_0 -- the albedo of the underlying surface. Calculations were also made for $\ell > 4/3$. These calculations (with $\omega \leq 1$) reveal correlations of the variation in $F_\downarrow(z)$ with increase in ℓ, and with decrease in ω, afford an estimate of the error and convergence of the several approximations, and show the role played by reflection from the underlying surface. The figure shows that calculations using different A_0 values do not yield a marked difference, therefore in the following we will consider only the case $A_0 = 0$. It is clear that in the case $\gamma = \gamma_R$ the virtually exact numerical solutions of the rigorous transfer equations, calculation based on the asymptotic formulas, and the solution of the equations in the Schwarzchild approximation virtually coincide. At the same time we see that the single-layer model for any γ and ω does not agree with the measurement results. /9

As already noted, analysis of the experimental curve [1] led to the conclusion that in the region of measurements there are two layers that differ in their optical properties. Therefore, all subsequent calculations were made for the model of the two-layer atmosphere.

Equations (9) and (10) were solved in each i-th layer ($i = 1, 2$) with tabulation with respect to the parameters $\tau^{(i)}$, $\omega^{(i)}$, and $\Gamma^{(i)}$, where $\tau^{(i)}$ is the total optical thickness of the i-th layer. The conditions of continuity of the one-way fluxes

$$F_{\uparrow}^{(2)}(\tau^{(2)}) = F_{\uparrow}^{(1)}(0) \tag{14}$$

$$F_{\downarrow}^{(2)}(\tau^{(2)}) = F_{\downarrow}^{(1)}(0) \tag{15}$$

were assigned at the boundary between the layers with $z_0 = 32$ km.

The flux $F_{\downarrow}^{(2)}(0)$ is assigned at the upper boundary of the upper layer ($i = 2$), equal to the measured flux, for $z = 49$ km. $A_0 = 0$, that is $F_{\uparrow}^{(1)}(0) = 0$ is assumed at the lower boundary of, i.e., the lower layer. The function $\tau^{(1)}(z)$ was assumed to be proportional to the function $p(\bar{z})$.

Figs. 2 and 3 present the results of calculations for two models. In the first of these, the upper layer ($i = 2$, 32 km $\leq z \leq$ 50 km) is optically thin, quite close to the Rayleigh layer: $\tau^{(2)} = 3$ for $\tau^{(2)}_{R,\lambda_{eff}} = 0.8$; and in the second model, the upper layer is optically dense: $\tau^{(2)} \approx 20$-50. In both cases the purely nonabsorbing Rayleigh lower layer was considered: $\tau^{(1)} \approx \tau^{(1)}_{R,\lambda_{eff}} = 9$.

The calculation results lead to the following conclusions:

a) The lower portion of the Venusian atmosphere is weakly /10 dust-filled, so that scattering here occurs in accordance with Rayleigh's law. This conclusion confirms the results of the analysis of experimental data given in [1] and is in agreement with the data of paper [15] to the effect that the wind velocity in the lower atmospheric layers is low, less than 1 m/sec. No detectable absorption was observed here. The possible deformation of the spectral composition of the radiation flux with $\lambda'_{eff} > \lambda_{eff}$, as calculations suggest, will not alter this conclusion. The convergence of the calculations and measurements in the lowest atmospheric layers can be improved even further, by setting $A_0 > 0$ (cf. Fig. 1).

b) Two alternative models are equally probable for the upper portion: model I is an optically thin, absorbing atmosphere ($\tau^{(2)} \approx 3$, $\omega^{(2)} < 1$); model II is an optically dense, purely scattering ($\tau^{(2)} \leq 50$, ${}^{(2)} = 1$) atmosphere.

Other variants permitting an estimation of the possible effect of changes in the main parameters are shown in each figure, along with the main curves representing calculations that are closest to the measurements. For model (I), the optical thickness $\tau^{(2)} \approx \approx 3\ \tau_R^{(2)}$, therefore it is natural to set $\Gamma^{(2)} > 0$. Here, as shown by Fig. 3, it is required to reduce (compared with the main variant $\Gamma^{(2)} = 0$, $\omega^{(2)} = 0.95$) the value of $\omega^{(2)}$. Evidently, the scattering conditions when $0 \leq \Gamma^{(2)} < 0.73$ and $0.90 < \omega^{(2)} \leq 0.95$ correspond to this model.

The second model is naturally associated with intensely elongated indicatrices. Calculations for pure scattering conditions with $\tau^{(2)} \approx 50$ and $\Gamma^{(2)} = 0.73$ agree satisfactorily with measurement results.

If we start from the estimate of the water vapor content in the Venusian atmosphere based on the results of gas analysis on

Venera 4 Interplanetary Automatic Station and the model of the /11
troposphere constructed based on experimental data, the level of condensation is attained near 60 km [8]. Both optical models of the 32-50 km layer we obtained then can be regarded as the result of the penetration of cloud particles (for example, owing to convection) into the underlying atmosphere. If few particles arrive (model I), significant absorption ($\omega \leq 0.95$) can be the manifestation of the absorption displayed in the cloud for $\lambda \leq 0.65$ m (ω of the cloud ≥ 0.9986, according to [9]). Here σ_{cl} [cl = cloud] $\gg \sigma^{(2)}$, and hence $\omega^{(2)} < \omega_{cl}$. In the second model we can consider the spreading of the cloud downward to the level $z \approx 35$ km with slight absorption: $\omega^{(2)} \approx \omega_{cl} = 1$. Note that this level corresponds to the boiling water at the appropriate T and P.

An independent control of the estimates given of $\omega^{(2)}$ can be obtained from the following considerations. Assume that in the 32-50 km layer there is a depth regime. Then $F_{\downarrow}(z) \sim e^{-k\tau}$, where k is represented approximately (cf. [11]) as

$$K = 2\sqrt{\frac{1-\omega}{\ell\omega}} \tag{16}$$

By calculating k based on the formula

$$K = \frac{1}{\tau} \ln \frac{F_1(50)}{F_1(32)} \tag{17}$$

for τ values corresponding to the models under consideration, from (16) we get $\omega^{(2)}_{mod\ I} \lesssim 0.96$ and $\omega^{(2)}_{mod\ II} \lesssim 0.999$, in good agreement with the estimates by the selection method.

Note that in the first model the scattering coefficient $\sigma_{mod\ I} = \sigma/H = 0.2\ km^{-1}$, and in the second $\sigma_{mod\ II} = 3.3\ km^{-1}$ for H = 15 km. Likewise, the absorption coefficient

$\alpha_{mod\ I} = (\sigma/\omega) - \sigma \approx 0.01\ km^{-1}$ and $\alpha_{mod\ II} \approx 0.005\ km^{-1}$ with /12
$\omega^{(2)}_{mod\ I} \approx 0.95$ and $\omega^{(2)}_{mod\ II} \approx 0.999$. That is, we can assume the absorbing properties in both models to be very similar, which confirms the hypothesis that cloud particles penetrate into the subcloud layer.

These estimates of the absorption coefficient can be verified by the following considerations. The Venusian albedo in the visible region is equal to approximately 80%. Transmission, as already indicated, is of the order of 1%. Thus, absorption must be of the order of 20%. The optical thickness of the cloud is approximately 50 and that of the subcloud layer is ~ 3 or ~ 50, depending on the model we chose. The mean photon path in a scattering medium, based on the estimates given in the work [17] is $\ell_{av} = nH$, where H is the thickness of the layer, $1 \leq n \leq 2$ with $\tau \leq 5$ and $3 \leq n \leq 6$ for $10 < \tau \leq 100$. Obviously, absorption is equal to $e^{-\alpha \ell_{av}}$. With $H_{cl} = 10$, $H_{subcl} = 15$ km [subcl = subcloud layer] and the above values of α, we can readily obtain an absorption of the order of 50% in both models. Thus, the absorption coefficient is validly estimated in order of magnitude and is approximately two to three times overstated.

From the scattering coefficient we can estimate the concentration of particles for their specific radius. Let us set $r \geq 10$ μm (assuming that coarse particles enter the subcloud layer), then by the formula

$$N = \frac{\sigma}{\pi r^2 \mathcal{K}} \tag{18}$$

where $\mathcal{K} \approx 2$ is the effective scattering cross section, we get $N_{mod\ I} \leq 0.32$ particles/cm^3 and $N_{mod\ II} \leq 5.25$ particles/cm^3.

In conclusion, we point out that both optical models of the subcloud atmosphere agree closely with the results of the work [1], and also with the known models of the reflection spectrum (cf., for example, [2]), by virtue of the small influence of the subcloud layers on reflection from the dense cloud layer. /13

The concept of a cloud layer with an optical density of the order of several tens and $0.99 \leq \omega \leq 1$ agrees with the measured values of $F_{\downarrow}(z)$ for $z = 49$ km.

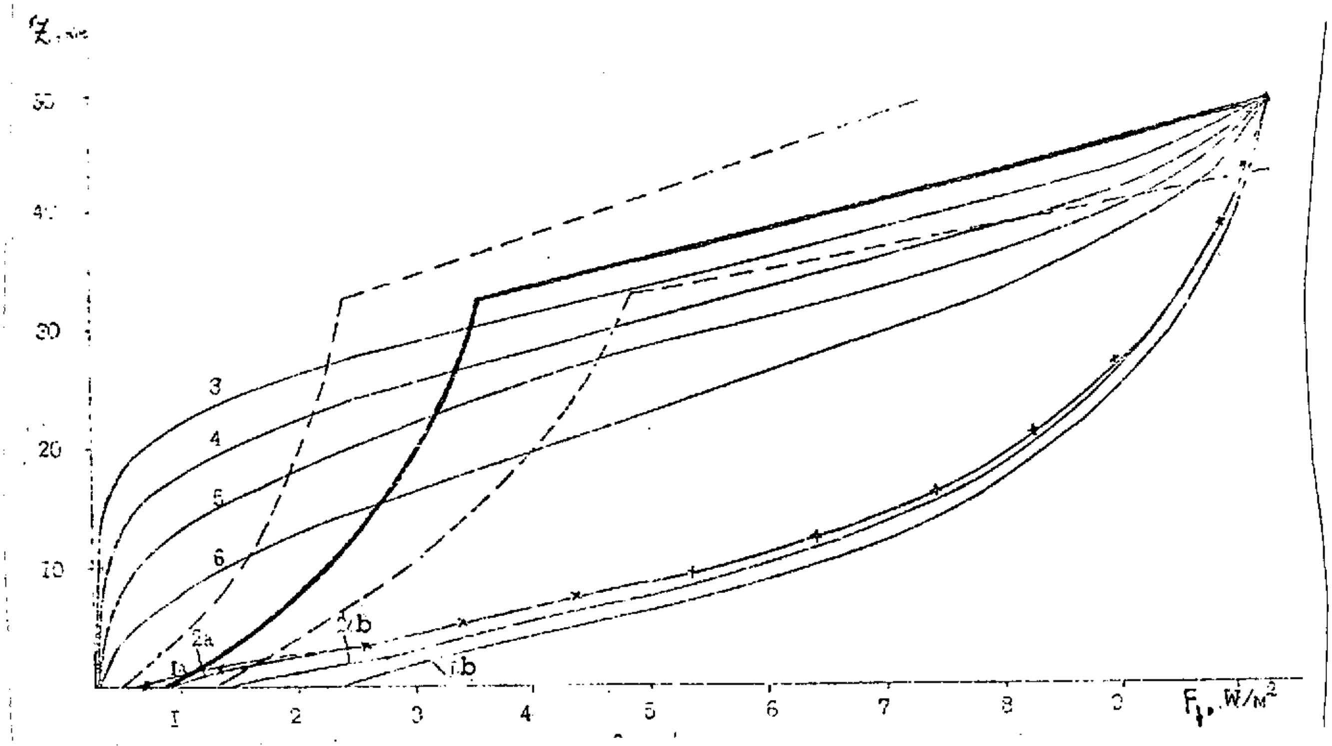

Fig. 1. Variation in illumination with altitude for a single-layer model. The bold line is the experimental curve, and the dashed lines represent the scattering of points. The crosses stand for the numerical solution of the transfer equation with $\omega = 1$, $A_0 = 0$ and $\gamma_R(\phi)$. /14

1a -- Calculations based on asymptotic formulas given in [12] for $\omega = 1$, $A_0 = 0$, and $\ell = 4/3$;

1b -- Calculations based on the asymptotic formulas given [12] with $\omega = 1$, $A_0 = 0$, $\ell = 4$;

2a -- Calculations based on the Schwarzchild method with $\omega = 1$, $A_0 = 0$, $\Gamma = 0$.

2b -- Calculations based on the Schwarzchild method with $\omega = 1$, $A_0 = 0.85$, $\Gamma = 0$;

Curves 3, 4, 5, and 6 represent calculations based on the Schwarzchild method for $\Gamma = 0$, $A_0 = 0$, and $\omega = 0.90$, 0.95, 0.975, and 0.99, respectively.

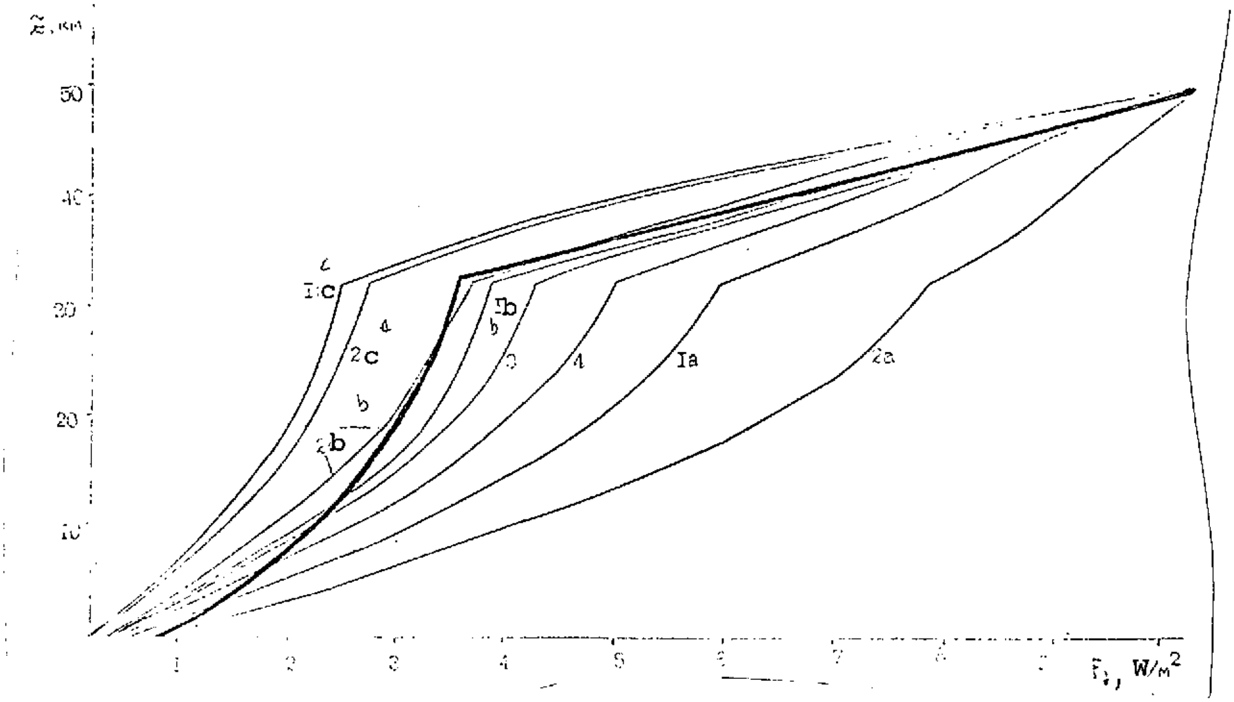

Fig. 2. Variation in illumination with altitude for a two-layer model. The bold line is the experimental curve. In all cases, $\delta^{(1)} = 1$, $\Gamma^{(1)} = 0$, and $\tau^{(1)} = 9$ in the lower layer. The parameters $\tau^{(2)}$, $\omega^{(2)}$, and $\Gamma^{(2)}$ are varied in the upper layer.

Ia - $\tau^{(2)}=3$, $\omega^{(2)}=0.95$, $\Gamma^{(2)}=0.73$;
Ib - $\tau^{(2)}=3$, $\omega^{(2)}=0.90$, $\Gamma^{(2)}=0.73$;
Ic - $\tau^{(2)}=3$, $\omega^{(2)}=0.80$, $\Gamma^{(2)}=0.73$;
2a - $\tau^{(2)}=3$, $\omega^{(2)}=I$, $\Gamma^{(2)}=0$;
2b - $\tau^{(2)}=3$, $\omega^{(2)}=0.95$, $\Gamma^{(2)}=0$;
2c - $\tau^{(2)}=3$, $\omega^{(2)}=0.90$, $\Gamma^{(2)}=0$;
3 - $\tau^{(2)}=5$, $\omega^{(2)}=0.95$, $\Gamma^{(2)}=0.73$;
4 - $\tau^{(2)}=3$, $\omega^{(2)}=0.95$, $\Gamma^{(2)}=0.53$.

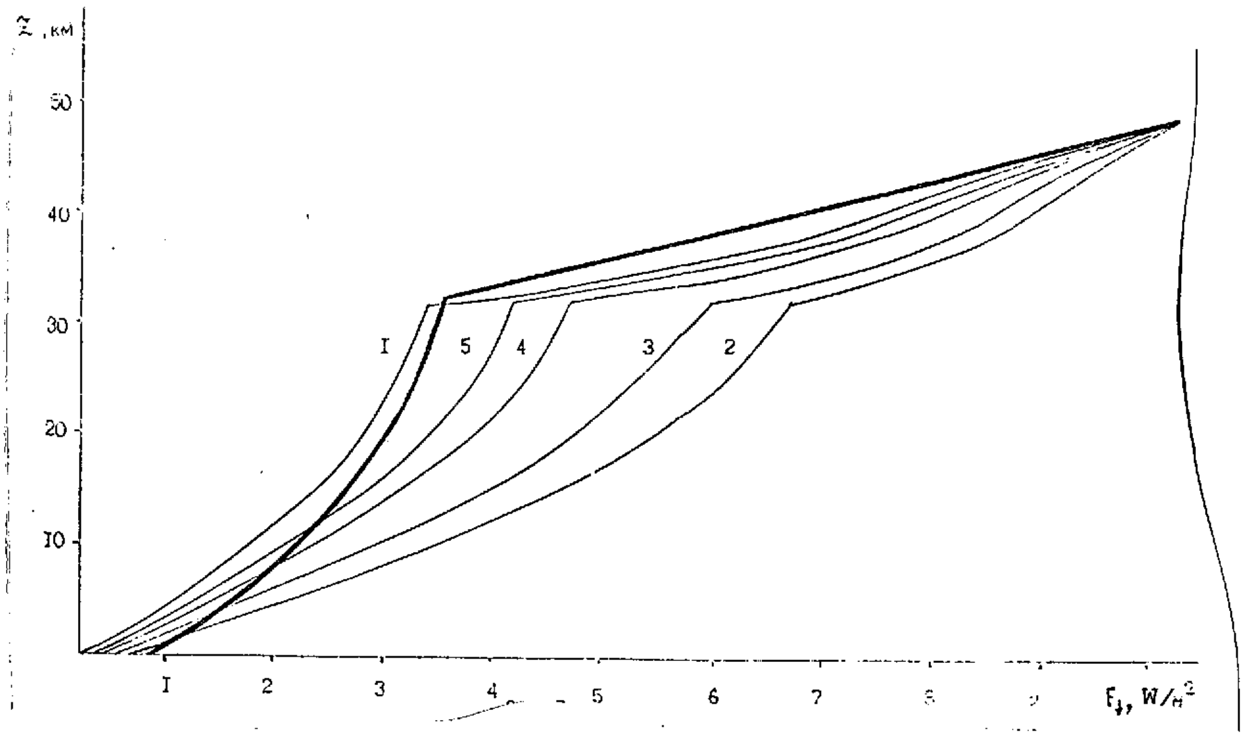

Fig. 3. Variation in illumination with altitude [illegible] of a two-layer model. The bold lines is the experimental line. In all cases: $\omega^{(1)} = \omega^{(2)} = 1$, $\Gamma^{(1)} = 0$, and $\tau^{(1)} = 9$. /15

I - $\tau^{(2)}=20$, $\Gamma^{(2)}=0$;
2 - $\tau^{(2)}=20$, $\Gamma^{(2)}=0,73$;
3 - $\tau^{(2)}=25$, $\Gamma^{(2)}=0,73$;
4 - $\tau^{(2)}=40$, $\Gamma^{(2)}=0.73$;
5 - $\tau^{(2)}=50$, $\Gamma^{(2)}=0.73$.

REFERENCES

1. Abduyevskiy, V. S., Marov, M. Ya., Moshkin, B. Ye., and Ekonomov, A. P., "Results of direct measurements of illumination in the atmosphere and on the surface of the planet Venus in the flight of Venera 8 interplanetary automatic station," Doklady AN SSSR, 1973 (in press). /16

2. Moroz, V. I., "The atmosphere of Venus," UFN 104(2) (1971).

3. Feygel'son, Ye. M., "Optical properties of the Venusian atmosphere and certain possibilities of the interpretation of measurements," Kosm. issl. 10(3) (1972).

4. Sharonov, V. V., Tablitsy dlya rascheta prirodnoy osveshchennosti i vidimosti, [Tables for Calculating Natural Illumination and Visibility], Moscow-Leningrad, 1945.

5. Tikhonov, A. N., "Solution of incorrectly formulated problems and the method of regularization," Doklady AN SSSR 151(3) (1963).

6. Tikhonov, A. N., "Regularization of incorrectly formulated problems," Doklady AN SSSR 153(1) (1963).

7. Turchin, V. F., Kozlov, V. P., and Malkevich, M. S., "Use of mathematical statistics in solving incorrect problems," UFN 102(3) (1970).

8. Marov, M. Ya., "Venus: a perspective at the beginning of planetary exploration," Icarus 16(3) (1972).

9. Galin, V. Ya., Dukashevich, N. L., and Feygel'son, Ye. M., "Reflection of solar light from the atmosphere of Venus," Doklady AN SSSR 197(2) (1971).

10. Sobolev, V. V., Perenos luchistoy energii i atmosferakh zvezd i planet, [Transfer of Radiative Energy in the Atmosphere of Stars and Planets], Moscow, 1956.

11. Sobolev, V. V., Rasseyaniye sveta v atmosferakh planet, [Scattering of Light in Planetary Atmospheres], Moscow, 1972.

12. Rozenberg, G. V., "Optical properties of thick layers of a homogeneous scattering medium," in the collection Spektroskopiya svetorasseivayushchikh sred, [Spectroscopy of Light-Scattering Media], Minsk, 1963.

13. Germogenova, T. A., and Konovalov, N. V., "Asymptotic characteristics of the solution of the transfer equation for the inhomogeneous layer problem," ZhVM and MV, 1971 (in press). /17

14. Zege, E. P., O dvukhpotokovom priblizhenii v teorii perenosa izlucheniya, [Two-Flux Approximation in the Theory of Radiation Transfer], Minsk, 1971.

15. Marov, M. Ya., Abduyevskiy, V. S., Kerzhanovich, V. V., Rozhdestvenskiy, M. K., Borodin, N. F., and Ryadov, O. P., "Measurements of temperature, pressure, and wind velocity in the atmosphere of Venus on the Venera 8 Interplanetary Automatic Station," Doklady AN SSSR 210(3) (1973).

16. Irvin, V., "Monochromatic phase curve and the albedo of Venus," Issledovaniya atmosfer Marsa i Venery, [Studies of the Atmospheresof Mars and Venus, a collection of articles], Leningrad, 1970.

17. Krasnokutskaya, L. L. and Feygel'son, Ye. M., "Calculations of infrared solar radiation fluxes in a cloudy atmosphere," Izvestiya AN SSSR, seriya FAO 13(5) (1972).